A Developmental Study to Design, Construct, and Test A Radiographic Phantom for Exposure Programming

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by

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ABSTRACT

A New Design in Radiographic Phantoms

for

Exposure Programming

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Radiologic Technology training programs based in colleges and universities are forced to make use of simulating devices such as phantoms and energized laboratories to supplement the clinical experience gained by the student technologists. The radiographic phantom which is the subject of this report is an attempt to provide a device which more accurately simulates the human body for purposes of experimentation with radiographic exposure programming.

This study involved the following activities:

1) a research phase to determine if a need for such a device did exist;

2) a development phase in which the target objects, the basic scattering medium, and the form of the phantom were selected, and a prototype was constructed;

3) Performing experiments and collection of data to evaluate the performance of the device;

The following recommendations resulted from the study:

1) A follow-up study could be attempted to determine the significance of the developed unit as an effective instructional device. A number of college based training programs in radiologic technology could be used to field test the pahntom. Following this evaluation period, data could be collected concerning the performance of the device. The data would be tabulated, and compiled into a final report.

2) A laboratory manual could be compiled which would list a selection of suggested experiments to be performed with the phantom to demonstrate the basic principles of radiographic quality and exposure programming.

3) This radiographic phantom, along with the laboratory manual mentioned in recommendation number two, could be commerically produced and made available to radiologic technology training programs and hospital radiology departments.

Accepted by:

[illegible], Chairman

Norman N. Roberts

[illegible]

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CHAPTER I

INTRODUCTION

From its inception until the early 1960's, the art and science of Radiologic Technology was predominently taught in hospitals. The mode of instruction took the form of on-the-job training. Students became proficient by performing radiographic examinations on patients under the direct supervision of radiologic technologists. Most of the training programs were located in hospitals with a large volume and diversity of patients and examinations, which enabled the students to have adequate experience in a wide variety of radiographic examinations, and with patients under many varied circumstances.

With the gaining popularity of associate degree technical programs in community and junior colleges, training programs in radiologic technology began to change. The theoretical aspects of the science became the responsibility of institutions of higher education while the hospitals retained the responsibility for the clinical experience needed by the student technologists.

College based training programs in radiologic technology typically offer about half of the clinical experience that a student would gain in a hospital based training program. Most college based programs use an energized lab facility to help offset this deficiency in clinical experience. Ideally, the lab simulates a hospital radiology department and is a supplement to the clinical aspect of the curriculum.

In conjunction with the lecture courses, the student performs many experiments to demonstrate basic principles of radiation safety, anatomy and positioning, radiation physics, and radiographic technique or "exposure programming" as it is sometimes called.

Statement of the Problem

The nature of this investigation dealt with the development and laboratory testing of a new type of radiographic phantom specifically designed for laboratory use to demonstrate the basic principles of exposure programming. College based training programs do not have access to a large file of radiographs to use as visual aids while discussing the factors that control radiographic quality. Students can not be exposed to radiation for experimental purposes to demonstrate radiographic principles, due to the harmful nature of repeated exposure to ionizing radiation. Acceptable substitutes for human beings must be used by student technologists in the x-ray laboratory. These substitutes, called radiographic phantoms, have been common to the art for many years. As a rule, they are in the form of a human anatomical structure or region and consist of bones imbedded in a plastic material. Each phantom model requires the same exposure as its human counterpart in order to produce a radiograph of acceptable diagnostic quality. Through the use of these phantoms, students develop skill in positioning an anatomic part in a particular manner to demonstrate specific anatomical structures. However, no single phantom has the versatility required to demonstrate the application of principles of exposure programming.

Signifiance of the Problem

Despite the fact that radiographic phantoms have been commonly used as instructional aids for many years, their versatility is indeed limited. The human body is constructed from many different materials, each of which interacts with, and absorbs radiation in a specific manner. This interaction is dependent upon the atomic number, density, and mass of the absorber, and the initial energy of the radiation used. The radiographic phantoms currently available are constructed of plastic and bone and are incapable of reproducing the varied density pattern radiographically associated with the process of differential absorption of radiation caused by a variety of materials. Thus, the available radiographic pahntoms do not adequately demonstrate the variations in radiographic density and contrast that result from changes in the quanity or penetrating power of the radiation exposure dose employed.

Limitations

This research project was conducted within the confines of the following limitations:

1. A search of the current literature, including existing domestic and foreign patents was made to ascertain the availability of an adequate phantom for technical evaluation.

2. A radiographic phantom was designed and a working model built. The applications of this phantom are limited to experimentation and demonstration of principles of radiographic quality.

3. Laboratory tests were conducted and the results recorded in terms of units of radiographic density. The values obtained are relative to

each other and the laboratory equipment used. They are not significant as absolute values.

4. The project was begun in 1975 and is complete with the presentation of this report.

Definition of Terms

For clarification and continuity in reading, the following terms are defined:

Radiographic Phantom - A material posessing about the same density and number of electrons per gram as living tissue. This material simulates living tissue for purposes of experimentation with doses of ionizing radiation and recording measurements of absorption and scattering of radiation.

Radiographic Density - Radiographic Density is defined as the amount of darkening of an x-ray film, or a certain area on the film. Radiographic density is due to a buildup of black metalic silver in the film's emulsion. This buildup of metalic silver is initiated by exposure of the silver bromide crystals in the film's emulsion to ionizing electromagnetic radiation, and completed during the developing process when the exposed crystals of AgBr are reduced to metalic silver by the organic reducing agents (Hydroquinone and Metol) in the developer solution. A numerical value is assigned to a given radiographic density according to the formula:

$$\text{density} = \log \frac{\text{incident light intensity}}{\text{transmitted intensity}}$$

Radiographic Contrast - Radiographic Contrast is a measure of the percentage of difference in density between adjacent densities on the radiograph. This difference is caused by the differential absorbtion process in which adjacent materials absorb varying quanities of radiation.

Radiographic Distortion - All radiographic images are false images. It is impossible to produce a radiographic image that is precisely the size and/or shape of the subject material. There are two forms of radiographic distortion. "Magnification" or size distortion, and "True" or shape distortion. With few exceptions, radiographic distortion has an adverse affect on the quality of the radiographic image and the radiographer must strive to minimize their effects.

Radiographic Definition - Radiographic definition is a measure of the sharpness and visability of the structure lines within the radiographic image.

Prime Factors of Radiography - Those factors which must be selected by the radiographer and programmed into the x-ray equipment prior to each radiographer exposure are called the "Prime Factors". Collectively these factors control the photographic effect on the x-ray film's emulsion according to the formula:

$$\text{Photographic Effect (PE)} = \frac{mA \times T \times KVP^2}{D^2}$$

where:

mA = Milliamperage or x-ray tube current employed.
T = Exposure time or duration of exposure measured in seconds or fractions there of.
KVP = measure of the potential difference applied between the cathode and anode of the x-ray tube. In diagnostic radiography, these values range in magnitude from 20 to 150 thousand volts.

D = the distance (measured in inches) between the source of the radiation is divergent, an inverse relationship exists between the quanity of radiation per unit area of x-ray film and the source-to-film distance. This inverse relationship is stated by the inverse Law as follows:

$$\frac{I}{i} = \frac{d^2}{D^2}$$

where:

I = New radiation intensity
i = Original radiation intensity
d = Original source-to-film distance
D = New source-to-film distance

Attenuation of Radiation - A reduction in the intensity of an x-ray beam occurs as the radiation interacts with and is absorbed by the material it is traveling through.

Roentgen(R) - The unit measure of radiation exposure. Its value is found by determining the amount of ionization of air produced by the radiation.

Grid - A device constructed of alternative strips of lead and a radiolucent material. The purpose of a grid is to selectively absorb scattered and secondary radiation.

Intensifying Screen - A device used to increase the effect of radiation on the x-ray film. An intensifying screen is constructed with a plastic base which is coated with a flourescent material such as calcium tungstate. These screens are incorporated into a cassette and are in direct contrast with the x-ray film.

CHAPTER II

REVIEW OF LITERATURE

During the months of July and August 1975, interviews were conducted with a number of educators and technical experts in the field of radiologic technology. None of these experts were aware of the existence of a phantom similar to that described in this study. The concensus of opinion was that the existing phantoms did not adequately demonstrate the principles of exposure programming, and that there was a need for this type of device.

No other studies similar in nature to this report were located. A review of material contained in the journal of the American Society of Radiologic Technology, Radiologic Technology again failed to disclose information regarding this type of phantom. (16) In addition to the review of scientific literature, the Law Offices of B. L. MacGregor of Englewood, Colorado were employed to conduct a search of foreign and domestic patents in an attempt to locate a radiographic phantom similar to that which is the subject of this report. At the completion of this search, no similar radiographic phantom had been issued Letters Patent. In June of 1978, notification was received from the Law Offices of B. L. MacGregor that Letters Patent had been granted and issued for this radiographic phantom. The preceding account is submitted to verify the originality of the phantom herein described.

Several radiographic phantoms with a limited number of densities are described in the scientific literature including the following:

I. The 3-M Corporation offers a set of phantoms which may be purchased individually or as a complete set. These phantoms are widely used, both in training programs and in radiology departments. The complete set includes the following anatomical structures: One full skull, one section of a skull, one thorax, one pelvis including lumbar segments, and proximal femori, one knee, one ankle and foot, one elbow, one wrist and hand, one breast. When purchased individually, they range in price from one hundred to more than three thousand dollars, depending upon the unit. (13) The anatomical accuracy of these phantoms is, in the opinion of this researcher, only fair.

The bony anatomy for each piece is cast in a clear plastic resin and formed to the surface contours of the corresponding human anatomical region. The unit may then be positioned in the same manner that its' human counterpart would be for the views which comprise the radiographic examination. Radiologic Technology students gain valuable experience in positioning anatomical parts and can check the accuracy of their positioning by producing radiographs of the phantoms.

II. The Alderson Research Laboritories, Inc. provided the first of the fully articulated phantom. In the form of an adult male patient, weighing about 150 pounds, this phantom functions basically the same as the articulated phantom produced by Humanoid Systems, Inc. (14) Being relatively large and heavy, most students find it to be a difficult phantom to position for examination. Though it has movable joints, these joints cannot be radiologically evaluated. Contrast agents may be introduced through access to various organ systems to simulate contrast studies of the stomach, colon and gall bladder. In addition to the full-body phantom, sectional phantoms are also available which are similar in nature and function to those provided by 3-M Company.

III. Humanoid Systems, Inc. offers a fully articulated phantom, called the Pixy, in the form of an adult female. Two versions of this full body phantom are available, a light weight unit weighing about 110 pounds. These models provide positioning experience for the student technologist and maybe radiographed to check positioning accuracy. (15) The full body phantoms are more difficult for the students to work with but are beneficial in that they are more closely simulate the human patient. One problem that remains to be worked out with all articulated phantoms is a method of providing moving joints for the upper and lower extremities that are anatomically accurate.

IV. In addition to the phantoms mentioned in the preceding sections, enterprising and creative technologists and instructors have designed and made their own phantoms. Some of these designs include: Leg of lamb or other cut meat; wet towels wrapped around a bone; paraffin or other wax around a bone; tray of water with a bone in it.

SUMMARY

Radiographic Phantoms have been common to the field of Radiologic Technology for many years. They are indispensible as both research tools, and instructional aids. A search of the literature indicates that a variety of phantoms can be readily purchased in a wide range of prices. However, neither the literature, nor the files of the patent office indicate the existence of a phantom such as that described in the following chapter.

CHAPTER III

PROCEDURE

Procedurally this research project was conducted in three parts: first, the existing phantoms would be evaluated to determine their effectiveness as teaching aids for the purpose of demonstrating the basic principles of radiographic technique, second, a phantom would be designed and built to meet the specific needs of instruction in the area of exposure programming, and third, a series of experiments would be designed and conducted to evaluate the effectiveness of this new phantom and the resultant data would be compiled and incorporated into a formal report on its effectiveness.

Evaluation of Existing Phantoms

This phase of the research project involved collaberation with various educators in the field of Radiologic Technology, most of whom were located in the Denver, Colorado area. (17) Both individual and group discussions were held in an attempt to identify some of the basic deficiencies of the existing phantoms. A concensus of opinion was reached that these phantoms did function adequately as teachnig aids in the area of radiographic positioning. Whereas it would be impossible for students to perform radiographic examinations on each other due to the danger of overexposure to radiation, these phantoms could be positioned by the student and radiographs made to evaluate the accuracy of their positioning techniques. However, due to the limited number of densities and the lack of variability inherent in the construction of the existing phantoms, their usefullness in demonstrating principles of technique was indeed limited.

Design of New Phantom

The first and most important material chosen for the phantom was the scattering medium. An electrolyte solution containing sodium, potassium, calcium magnesium, bicarbonate, chloride, phosphate, and sulfate ions was chosen. This electrolyte solution was chosen because it is identical to the fluid which accounts for seventy per cent of the total body weight.

The next step in the process was to identify other materials commonly found in the body or contrast agents introduced for purposes of radiographic examination. An obvious component was bone, and for the purposes of this phantom, the proximal end of a human femur was selected. Another common substance in the human body is gas which is introduced into this phantom via a sealed container. Three seperate containers filled with iodine in solution were selected for inclusion because such solutions are commonly used as contrast agents during radiographic examinations. The concentrations of iodine are 50%, 25%, and 12 1/2%. Two small containers of another iodine solution commonly used in examination of the female reproductive system are also included, one at twice the concentration of the other. A container was prepared with two space-occupying nodules and partially filled with a suspension of barium sulfate and heavy molasses. The purpose of this object is to simulate a portion of the gastro-intestinal tract filled with barium sulfate for radiographic examination. A small bladder containing an iodine soultion and several small radiolucent stones is also included to demonstrate the effect of the variations of penetrating power of the radiation employed.

The form chosen for the phantom was that of a rectangular box eight inches wide by ten inches long by six inches deep. This format makes the phantom relatively easy to handle. It also allows the phantom to be used with eight by ten inch x-ray film which is less expensive to use than larger films. The depth of the phantom gives it an overall density equivalent to a human abdomen measuring approximately fifteen centimeters which is slightly less than the average adult abdomen. It is easily possible to increase the overall density of the phantom to duplicate a larger abdomen merely by placing a radiolucent tray on the phantom and filling the tray to the desired patient measurement with water. A tube, sealed against the liquid within the container and communicating with its external surface was also included. The purpose of this chamber is to allow introduction of various objects to the phantom for experimentation and evaluation within the environment of the phantom. This chamber would also allow an ionization chamber to be placed within the phantom and measurements of internal doses of radiation to be recorded.

Collection of Data

The objective of the experiments discussed in this section of the study was to test the effectiveness of the phantom as a device capable of demonstrating radiographic principles. Each of the principles tested is basic to an understandig of exposure programming, this researcher did not claim discovery of any new radiographic principles as a result of the experiments described in this section.

Experiment I

The purpose of this experiment was to evaluate the ability of the phantom to demonstrate a direct relationship between the quanity of radition generated for a given exposure and the resultant radiographic density and contrast. The variable factor was mAS which controls the amount of radiation generated. Three exposures were delivered to the phantom and the resultant images recorded on Kodak RP54 x-ray film. The densities representing the target objects were measured with a Sakura densitometer. These values are listed in Table 1.

TABLE 1

Radiographic Densities recorded at 20 mAS
Exposure 1: 200 mA--1/10--130 KVP--40" TFD (Mean 41.05)

TARGET OBJECT	DENSITY	CONTRAST
#1	2.0	42.50
#2	1.15	50.00
#3	1.00	55.00
#4	0.90	45.00
#5	1.10	32.50
#6	1.35	60.00
#8	0.80	60.00
#9	1.90	05.00
Chamber	2.40	20.00
Mean	1.45	41.05

The first column lists the target object contained within the phantom. The second column lists radiographic density recorded for the target object. The third column lists the difference in density (as a percentage value) between the target object and the electrolyte.

Table 2 lists the radiographic densities resulting from an exposure of 40 mAS and 130 KVP.

TABLE 2

Radiographic Densities recorded at 40 mAS
Exposure 2: 200mA--1/5--130 KVP--40" TFD (Mean 24.14)

TARGET OBJECT	DENSITY	CONTRAST
background	2.60	
#1	2.00	23.08
#2	1.90	26.92
#3	1.70	34.62
#4	1.90	26.92
#5	2.10	19.23
#6	1.60	38.46
#8	1.60	38.46
#9	2.55	01.92
Chamber	2.80	07.69
Mean	2.26	24.14

The first column lists the target object contained within the phantom. The second column lists the radiographic density recorded for the target object. The third column lists the difference in density (as a %value) between the target object and the electrolyte.

Table 3 lists the radiographic densities resulting from an exposure of 80 mAS and 130 KVP.

TABLE 3

Radiographic Densities recorded at 80 mAS
Exposure 4: 200 mA--2/5--130 KVP--40" TFD (Mean 11.11)

TARGET OBJECT	DENSITY	CONTRAST
background	2.90	
#1	2.60	10.34
#2	2.50	13.79
#3	2.40	17.24
#4	2.58	11.03
#5	2.65	08.62
#6	2.45	15.52
#8	2.30	20.69
#9	2.90	00.00
Chamber	2.98	02.76
Mean	2.88	11.11

The first column lists the target objects contained within the phantom. The second column lists the radiographic density recorded for the target object. The third column lists the difference in density (as a % value) between the target object and the electrolyte.

Experiment II

The purpose of this experiment was to demonstrate the direct relationship that exists between the penetrating power of the radiation and radiographic density. Six exposures were made. The Kilovoltage for the initial exposure was 74. Each consecutive exposure increased the kilovoltage by 10. The final exposure was executed with KVP value of 124. The mAS remained constant at a value of 100 for each of the exposures. The exposures were recorded on Kodak RP54 x-ray film. A Sakura densitometer, Model PDA-80 was used to measure the density values. Tables 4 through 9 contain the density values recorded for the exposures.

Table 4 lists the radiographic densities resulting from an exposure of 100 mAS and 74 KVP.

TABLE 4

Radiographic Densities recorded at 74 KVP
Exposure 1: 100mA--1 second74-- KVP--40" TFD (Mean 80.02%)

TARGET OBJECT	DENSITY	CONTRAST
background	1.4	
#1	0.3	78.57
#2	0.25	82.14
#3	0.2	85.71
#4	0.3	78.57
#5	0.3	78.57
#6	0.2	85.71
#8	0.2	85.71
#9	1.0	28.57
Chamber	2.05	46.42
Mean	.62	80.02

The first column lists the target objects contained within the phantom. The second column lists the radiographic density recorded for the target object. The third column lists the difference in density (as a % value) between the target object and the electrolyte.

Table 5 lists the radiographic densities resulting from an exposure of 100 mAS and 84 KVP.

TABLE 5

Radiographic Densities recorded at 84 KVP
Exposure 2: 100 mA-- 1 second--84 KVP--40" TFD (Mean 63.05)

TARGET OBJECT	DENSITY	CONTRAST
background	2.0	
#1	0.75	62.5
#2	0.6	70.0
#3	0.4	80.0
#4	0.5	75.0
#5	0.8	60.0
#6	0.4	80.0
#8	0.4	80.0
#9	1.7	15.0
Chamber	2.9	45.0
Mean	1.05	63.05

The first column lists the target objects contained within the phantom. The second column lists the radiographic density recorded for the target object. The third column lists the difference in density (as a % value) between the target object and the electrolyte.

Table 6 lists the radiographic density resulting from an exposure of 100 mAS and 94 KVP.

TABLE 6

Radiographic Densities recorded at 94 KVP
Exposure 3: 100 mA--1 second--94 KVP--40" TFD (Mean 42.85)

TARGET OBJECT	DENSITY	CONTRAST
background	2.45	
#1	1.4	42.85
#2	1.2	51.02
#3	1.0	59.18
#4	1.2	51.02
#5	1.5	38.77
#6	0.9	63.27
#8	0.9	63.27
#9	2.2	10.20
Chamber	2.6	6.12
Mean	1.54	42.85

The first column lists the target objects contained within the phantom. The second column lists the radiographic density recorded for the target object. The third column lists the difference in density (as a % value) between the target object and the electrolyte.

Table 7 lists the radiographic densities resutling from an exposure of 100 mAS and 104 KVP.

TABLE 7

Radiographic Densities recorded at 104 KVP
Exposure 4: 100 mA--1 second--104 KVP--40" TFD (Mean 24.44)

TARGET OBJECT	DENSITY	CONTRAST
background	2.5	
#1	1.95	22
#2	1.8	28
#3	1.6	36
#4	1.8	28
#5	2.0	20
#6	1.5	40
#8	1.5	40
#9	2.5	0
Chamber	2.65	6
Mean	1.98	24.44

The first column lists the target objects contained within the phantom. The second column lists the radiographic density recorded for the target object. The third column lists the difference in density (as a % value) between the target object and the electrolyte.

Table 8 lists the radiographic densities resulting from an exposure of 100 mAS and 114 KVP.

TABLE 8

Radiographic Densities recorded at 114 KVP
Exposure 8: 100 mA--1 second--114 KVP--40" TFD (Mean 13.63)

TARGET OBJECT	DENSITY	CONTRAST
background	2.65	
#1	2.4	9.43
#2	2.3	13.21
#3	2.1	20.75
#4	2.3	13.21
#5	2.35	11.32
#6	2.0	24.53
#8	2.0	24.53
#9	2.65	0
Chamber	2.8	5.66
Mean	2.36	13.63

The first column lists the target objects contained within the phantom. The second column lists the radiographic density recorded for the target object. The third column lists the difference in density (as a % value) between the target object and the electrolyte.

Table 9 lists the radiographic densities resulting from an exposure of 100 mAS and 124 KVP.

TABLE 9

Radiographic Densities recorded at 100 mAS and 124 KVP
Exposure 6: 100 mA--1 second--124 KVP--40" TFD (Mean 19.92)

TARGET OBJECT	DENSITY	CONTRAST
background	2.8	
#1	2.55	8.92
#2	2.50	10.71
#3	2.45	12.50
#4	2.50	10.71
#5	2.6	7.14
#6	2.3	17.86
#8	2.3	17.86
#9	2.8	0
Chamber	2.9	3.57
Mean		19.92

The first column lists the target objects contained within the phantom. The second column lists the radiographic density recorded for the target object. The third column lists the difference in density (as a % value) between the target object and the electrolyte.

Experiment III

The objective of this experiment was to evaluate the ability of the phantom to clearly demonstrate the function of a radiographic grid. Two exposures were made with identical technical factors. The first exposure was made with 12:1 ratio moving grid in place. The second exposure was made after the grid had been removed. The densities were recorded on Kodak RP54 x-ray film. A Sakura densitometer, model PDA-80 was used to measure these density values.

Table 10 lists the densities resulting from an exposure of 50 mAS and 80 KVP with a 12:1 moving grid installed between the phantom and the x-ray film.

TABLE 10

Radiographic Densities recorded using 12:1 Grid
Exposure 1: 100 mA--1/2 second--80 KVP (Mean 62.88)

TARGET OBJECT	DENSITY	CONTRAST
background	.9	
#1	.15	83.33
#2	.8	11.11
#3	.05	94.44
#4	.15	83.33
#5	.1	88.89
#6	.7	22.22
#8	.05	94.44
#9	.5	44.44
Chamber	1.6	43.75
Mean		62.88

The first column lists the target objects contained within the phantom. The second column lists the radiographic density recorded for the target object. The third column lists the difference in density (as a % value) between the target object and the electrolyte.

Experiment IV

The purpose of this experiment was to evaluate the ability of the phantom to demonstrate the realtionship that exists between radiographic density and contrast, and the source-to-film distance. The initial source-to-film distance chosen was forty inches. A second exposure was made with the distance reduced from forty, to thirty inches. The technical factors chosen for the experiment were 100 mA, 1/2 second, and 80 KVP. These facotrs were used for both exposures. Radiographic densities resulting from these exposures were recorded on Kodak RP54 x-ray film, and measured with a Sakura densitometer, model PDA-80.

Table 11 lists the radiographic densities resulting from an exposure of 50 mAS and 80 KVP. The 12:1 Grid has been removed from between the phantom and the x-ray film for this exposure.

TABLE 11

Radiogaphic Densities recorded with 12:1 Grid removed
Exposure 3: 100 mA--1/2 second--80 KVP (Mean 12.5)

TARGET OBJECT	DENSITY	CONTRAST
background	2.8	
#1	2.0	
#2	1.95	2.5
#3	2.0	0
#4	2.0	0
#5	2.3	15
#6	2.1	5
#8	2.3	15
#9	2.5	25
Chamber	3.0	50
Mean		12.5

The first column lists the target objects contained within the phantom. The second column lists the radiographic density recorded for the target object. The third column lists the difference in density (as a % value) between the target object and the electrolyte.

Table 12 lists the densities and contrast values resulting from an exposure made at a 40 inch source-to-film distance with exposure factors of 100mA, 1/2 second, 80 KVP.

TABLE 12

Radiographic Densities recorded at 40" source-to-film distance
Exposure 1: 100 mA--1/2 second--80 KVP (Mean 62.88)

TARGET OBJECT	DENSITY	CONTRAST
background	.9	
#1	.15	83.33
#2	.8	11.11
#3	.05	94.44
#4	.15	83.33
#5	.1	88.89
#6	.7	22.22
#8	.05	94.44
#9	.5	44.44
Chamber	1.6	43.75
Mean		62.88

The first column lists the target objects contained within the phantom. The second column lists the radiographic density recorded for the target object. The third column lists the difference in density (as a % value) bewteen the target object and the electrolyte.

Table 13 lists the densities and contrast values resulting from an exposure made at 30 inch source-to-film distance with technical factors of 100 mA, 1/2 second, and 80 KVP.

TABLE 13

Radiographic Densities recorded at 30" source-to-film distance
Exposure 1: 100 mA--1/2 second--80 KVP (Mean 79.37)

TARGET OBJECT	DENSITY	CONTRAST
background	1.7	
#1	.3	82.35
#2	.1x5	91.18
#3	.1x0	94.12
#4	.2	88.24
#5	.3	82.35
#6	.15	91.18
#8	.1	94.12
#9	.7	58.82
Chamber	2.5	32.00
Mean	.62	79.37

The first column lists the target objects contained within the phantom. The second column lists the radiographic density recorded for the target object. The third column lists the difference in density (as a % value) between the target object and the electrolyte.

Experiment V

The purpose of this experiment was to evaluate the ability of the phantom to demonstrate the difference in radiographic density and contrast caused by the type and speed of the intensifying screens selected for use during the radiographic exposure. The initial exposure for this experiment involved the use of Radalin par speed intensifying screens mounted in a 10x12 inch Halsey cassette. The technical factors selected were: 100 mA, 1/2 second, and 80 KVP. The exposure was made with a 40 inch source-to-film distance.

Table 14 lists the densities and contrast values resulting from an exposure made at a 40 inch source-to-film distance with exposure factors of 100 mA, 1/2 second, and 80 KVP.

TABLE 14

Radiographic Densities resulting from par speed intensifying screens
Exposure 1: 100 mA--1/2 second--80 KVP (Mean 62.88)

TARGET OBJECT	DENSITY	CONTRAST
background	.9	
#1	.15	83.33
#2	.8	11.11
#3	.05	94.44
#4	.15	83.33
#5	.1	88.89
#6	.7	22.22
#8	.05	94.44
#9	.5	44.44
Chamber	1.6	43.75
Mean		62.88

The first column lists the target objects contained within the phantom. The second column lists the radiographic density recorded for the target object. The third column lists the difference in density (as a % value) between the target object and the electrolyte.

Experiment VI

The purpose of this experiment was to evaluate the ability of the phantom to demonstrate the relationship that exists between the quality and quantity of radiation delivered to an object and the measurement of radiation within the object. For this experiment, a Victoreen 440 R meter was used to measure the amount of internal radiation. A five roentgen ionization chamber was placed within the phantom via the flotation chamber located two and one-half inches below the upper surface of the phantom. The initial exposures were made with the electrolyle removed from the phantom, and the exposure field confined to the margins of the ionization chamber. The exposures were then repeated with the field expanded to the dimensions of the phantom.

The electrolyte was reintroduced to the phantom and each of the exposures was repeated in an attempt to determine the effect of a scattering medium on internal levels of radiation. The data recorded as a result of this experiment appear in the following tables.

Table 15 lists the densities resulting from an exposure made with exposure factors of 100 mA, 1/2 second, and 80 KVP and a 40 inch source-to-film distance. However, for this exposure, a Kodak x-omatic cassette containing Quante 2 intensifying screens was substituted for the Halsey casstette with par speed screens. The radiographic densities were recorded on Kodak RP54 x-ray film and measured with a Sakura densitometer, Model PDA-80.

TABLE 15

Radiographic Densities resulting from Quanta II Intensifying
Exposure 1: 100 mA--1/2 second--80 KVP (Mean 60.20)

TARGET OBJECT	DENSITY	CONTRAST
background	2.8	
#1	1.2	57.14
#2	.8	71.43
#3	.4	85.71
#4	.7	75.00
#5	1.0	64.29
#6	.5	82.14
#8	.4	85.71
#9	2.5	10.71
Chamber	3.1	9.68
Mean	1.34	60.20

The first column lists the target objects contained within the phantom. The second column lists the radiographic density recorded for the target object. The third column lists the difference in density (as a % value) between the target object and the electrolyte.

Experiment VI

The purpose of this experiment was to evaluate the ability of the phantom to allow internal radiation levels to be measured during radiographic exposures. A Victoreen R meter with a fine Roentgen ionization chamber was used to measure the radiation levels produced during the experiment. The ionization chamber was placed in the flotation chamber located at a depth of two and one half inches beneath the upper surface of the phantom. Exposures were made with various KVP and mAS settings. The initial exposures were made with the electrolyte solution removed from the phantom and the exposure field confined to the ionization chamber. Three exposures were repeated with the exposure field expanded to the dimensions of the phantom. Each of these exposures was repeated with the electrolyte solution in the phantom. The data resulting from the experiment were then tabulated and compared.

Table 16 lists the internal radiation levels recorded in the absence of a scattering medium at 120 KVP with mAS as the variable factor.

TABLE 16

Internal Radiation Levels with no Scattering Medium

mAS	Confined Field	Expanded Field
10	.10R	.10R
20	.20R	.20R
30	.30R	.39R
40	.38R	.50R
50	.50R	.62R
60	.51R	.71R
80	.82R	.92R
100	1.00R	1.20R
Mean	.46R	.58R

The first column indicates the mAs value selected. The second column indicates the radiation level with a confined exposure field. The third column indicates the radiation level with an expanded exposure field.

Table 17 lists the internal radiation levels recorded with the scattering medium at 120 KVP with mAS as the variable factor.

TABLE 17

Internal Radiation Levels recorded with Scattering Medium

mAS	Confined Field	Expanded Field
10	.10R	.20R
20	.20R	.30R
30	.30R	.50R
40	.35R	.60R
50	.45R	.75R
60	.58R	.80R
80	.70R	1.05R
100	.90R	1.40R
Mean	.45R	.70R

The first column indicates the mAS value selected. The second column indicates the radiation level with a confined exposure field. The third column indicates the radiation level with an expanded exposure field.

Table 18 lists the internal radiation levels recorded in the absence of the scattering medium at 100 mAS with KVP as the variable factor.

TABLE 18

Internal Radiation Levels recorded with no Scattering Medium

KVP	Confined Field	Expanded Field
50	.11R	.09R
60	.20R	.20R
70	.30R	.30R
80	.32R	.40R
90	.41R	.60R
100	.70R	.80R
110	.87R	1.00R
120	1.01R	1.20R
Mean	.49R	.57R

The first column indicates the mAS value selected. The second column indicates the radiation level with a confined exposure field. The third column indicates the radiation level with an expanded exposure field.

Table 19 lists the internal radiation levels recorded with the scattering medium at 100 mAS with KVP as the variable factor.

TABLE 19

Internal Radiation Levels recorded with Scattering Medium

KVP	Confined Field	Expanded Field
50	.05R	.10R
60	.10R	.20R
70	.20R	.30R
80	.30R	.40R
90	.40R	.60R
100	.50R	.90R
110	.60R	1.10R
120	.80R	1.35R
Mean	.37R	.62R

The first column indicates the mAS value selected. The second column indicates the radiation level with a confined exposure field. The third column indicates the radiation level with a expanded exposure field.

CHAPTER IV

ANALYSIS OF THE DATA

The information collected as a result of the experiments preformed with the radiographic phantom was organized into tables listing the mean average density and contrast values for each radiograph produced. The data were then analyzed in attempt to compare the experimental results to those results indicated by the basic principles of exposure programming. The values obtained are valid only as relative values, determined by the equipment used.

Experiment I

The objectives of this experiment was to evaluate the ability of the phantom to demonstrate the effect of mAS on radiographic density and contrast.

Table 20 lists the mean density and contrast values recorded for each of the three exposures produced during this experiment.

TABLE 20

The effect of mAS on Radiographic Density and Contrast

RADIOGRAPH	DENSITY	CONTRAST
1-20 mAS	1.45	41.05%
2-40 mAS	2.20	24.14%
3-80 mAS	2.88	11.11%

The first column lists the experimental variable. The second column lists the mean average density recorded on the x-ray film. The third column lists the average contrast racorded for each radiograph.

The average values of radiographic density listed in this table indicate a direct relationship between the mAS selected and the radiographic density produced by the exposure. The experimental results are consistent with the basic principle which states that radiographic density is controlled by mAS when all other factors remain constant.

The average contrast values listed in the third column indicate that radiographic contrast has decreased in each of the consecutive radiographs, thus demonstrating an inverse relationship between the density and contrast. This finding is consistent with basic principles.

RESULTS: Analysis of the data indicated that the phantom met the objective to clearly demonstrate these basic principles.

Experiment II

The objective of this experiment was to evaluate the ability of the phantom to deomnstrate the effect of KVP on radiographic density and contrast.

TABLE 21

Effect of Kilovoltage on Radiographic Density and Contrast

RADIOGRAPH	DENSITY	CONTRAST
4-74 KVP	.62	80.02
5-84 KVP	1.05	63.05
6-94 KVP	1.54	42.85
7-104 KVP	1.98	24.44
8-114 KVP	2.36	13.63
9-124 KVP	2.57	9.92

The first column lists the experimental variables. The second column lists the mean average density recorded on the x-ray film. The third column lists the average contrast recorded for each radiograph.

The average values of radiographic density listed in table 21 indicate that radiographic density increased as the penetrating power of the radiation increased, thus demonstrating a direct relationship between these factors. This demonstration is consistent with the basic principles.

The data indicates that there is an inverse relationship between the KVP selected and the average contrast as listed in column 3. This finding is consistent with the basic principle describing the relationship between the KVP and radiographic contrast. Analysis of the data indicates that the phantom has performed satisfactorily to demonstrate these basic principles.

RESULTS: Analysis of the data indicate that the phantom has met the objective of clearly demonstrating these basic principles.

Experiment III

The objective of this experiment was to evaluate the ability of the phantom to demonstrate the effect on radiographic density and contrast produced by a radiographic grid.

Table 22 lists the average radiographic density and contrast values recorded for each of the exposures produced during this experiment.

TABLE 22

The Effect of a Grid on Radiographic Density and Contrast

RADIOGRAPH	DENSITY	CONTRAST
Grid Exposure	.45	62.88%
non Grid Exposure	2.10	12.50%

The first column lists the experimental variable. The second column lists the average density recorded for each radiograph. The third column lists the average contrast recorded for each radiograph.

The average values of radiographic density listed in this table indicate greater average density for the radiograph produced without the grid positioned between the phantom and the x-ray film. A comparison of the average contrast values listed in the table indicates greater contrast on the radiograph produced with the grid placed between the phantom and the x-ray film. These findings are consistent with the purpose of a grid.

RESULTS: Analysis of the data indicated that the phantom met the objective of the experiment to clearly demonstrate the purpose of a radiographic grid.

Experiment IV

The objective of this experiment was to evaluate the ability of the phantom to clearly demonstrate the effect on radiographic density and contrast produced by variation in source-to-film distance when all other factors remain constant.

Table 23 lists the average radiographic density and contrast values recorded for each radiograph produced during this experiment.

TABLE 23

Effect of Source-to-Film Distance on Radiographic Density and Contrast

RADIOGRAPH	DENSITY	CONTRAST
40" Distance	.45	12.88%
30" Distance	.62	79.37%

The first column lists the experimental variable. The second column lists the average density recorded for each radiograph. The third column lists the average contrast recorded for each radiograph.

The average values for radiographic density listed in this table indicate greater density for the radiograph produced with a thirty-inch source-to-film distance than with a forty-inch source-to-film distance. A comparison of the average contrast values listed in the third column indicate greater contrast in the radiograph produced with a thirty-inch source-to-film distance. These findings are consistent with basic principles.

RESULTS: Analysis of the data indicates that the phantom met the objective of the experiment to clearly demonstrate the effect of source-to-film distance on radiographic density and contrast.

Experiment V

The objective of this experiment was to evaluate the ability of the phantom to demonstrate the effect of intensifying screen speed on radiographic density and contrast.

Table 24 lists the mean density and contrast values recorded for each of the radiographs produced during this experiment.

TABLE 24

Effect of Intensifying Screen Speed on Radiographic Density and Contrast

RADIOGRAPH	DENSITY	CONTRAST
Par Speed Screens	.45	62.88%
High Speed Screens	1.34	60.20%

The first column lists the experimental variable. The second column lists the average density recorded for each radiograph. The third column lists the average contrast recorded for each radiograph.

The average values for radiographic density listed in this table indicate greater density for the radiograph produced with the high speed intensifying screens. A comparison of the average contrast values listed in the third column indicate slightly greater contrast in the radiograph produced with the par speed intensifying screens. These findings are consistent with basic principles.

RESULTS: Analysis of the data indicate that the phantom met the objective of the experiment to clearly demonstrate the principles involved.

Experiment VI

The objective of this experiment was to evaluate the ability of the phantom to allow internal radiation levels to be recorded during radiographic exposures. These internal readings were obtained with an ion chamber placed within the flotation chamber in the phantom. The data gathered from this experiment demonstrate an increase in internal radiation levels corresponding to increases in KVP, mAS, exposure field size and also the presence of a scattering medium.

Results: Analysis of the data indicated that the phantom met the objective of this experiment to measure radiation levels within the phantom during radiographic exposure. This finding was most significant in light of the fact that none of the readily available phantoms were capable of performing this function.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This research project was undertaken in an attempt to produce a radiographic phantom capable of demonstrating a greater variety of the basic principles governing radiographic quality to student technologists. The research involved identification of the shortcomings of the existing phantoms and also in the areas where they performed well. The phantom designed and built was original in nature enough to meet the criteria required to be granted Letters Patent. No claim is made to discovery of any new principles controlling radiographic quality. The value of this phantom lies in it's versatility and the clarity with which it demonstrates these basic principles.

Conclusions

Based on the findings of this study, the following conclusions may be reached:

1) The radiographic phantoms presently in use are not capable of demonstrating all of the basic principles controlling radiographic quality.

2) The available phantoms contain fewer densities and have less versatility than the phantom which is the subject of this report.

3) The experimental phantom is relatively compact and easily used and adequately demonstrates the basic principles of exposure programming.

Recommendations

Based on the findings of this study, the following recommendations are made:

1) A followup study could be attempted to determine the significance of the developed unit as an effective instructional device. A number of college based training programs in radiologic technology could be used to field test the experimental phantom. Following this evaluation period, data could be collected concerning the performance of the phantom. The data would be tabulated, and compiled into a final report.

2) A laboratory manual could be compiled which would list a selection of suggested experiments to be performed with the phantom which would demonstrate exposure programming.

3) This radiographic phantom, along with the laboratory manual mentioned in recommendation number two could be commercially produced and made available to radiogolic technology training programs and hospital radiology departments.

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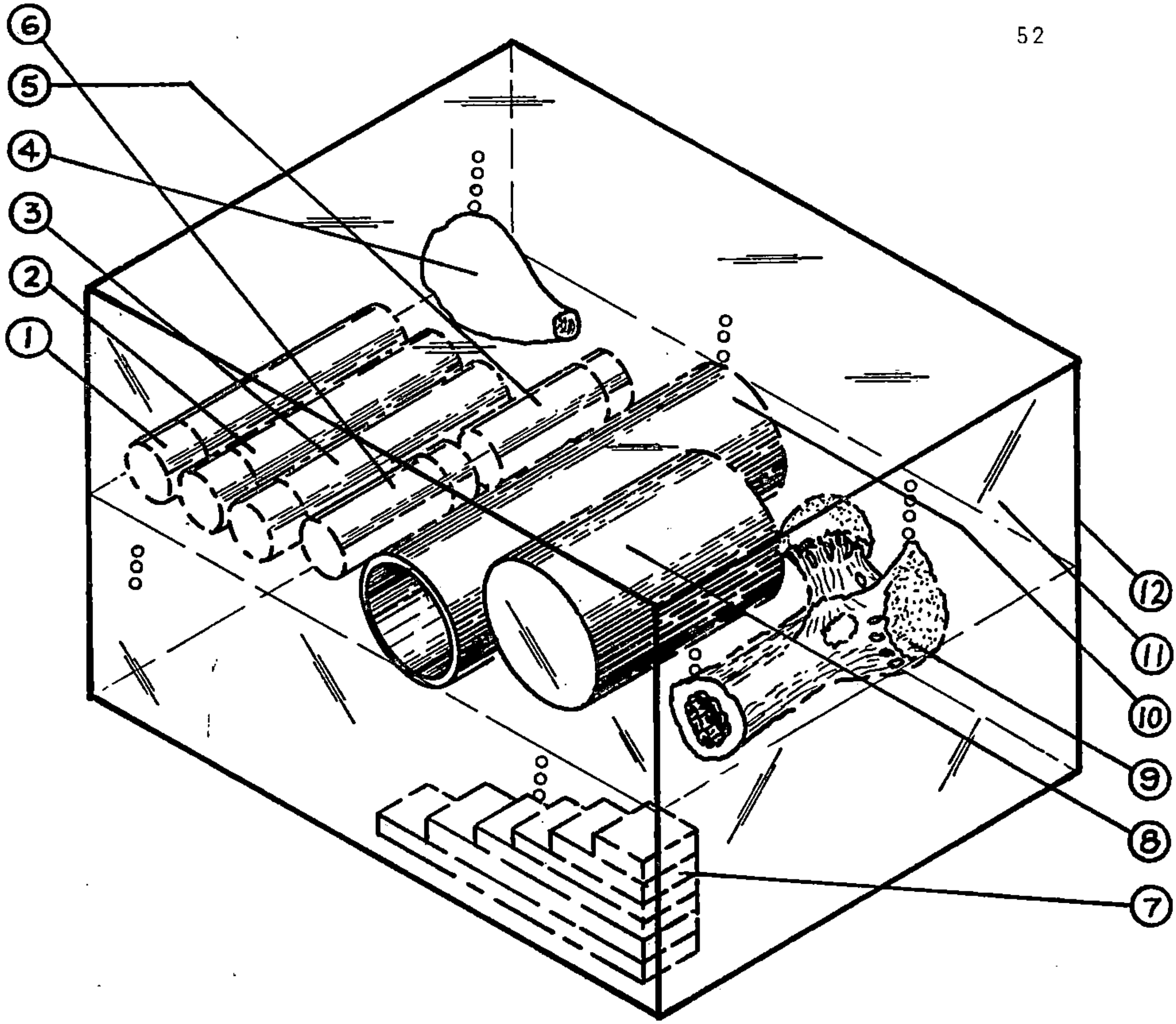
APPENDIX A

ISOMETRIC ILLUSTRATION OF EXPERIMENTAL PHANTOM WITH INDEX OF TARGET OBJECTS

INDEX OF TARGET OBJECTS
LOCATED WITHIN EXPERIMENTAL PHANTOM

1. Aqueous solution containing 12.5% iodine by volume.
2. Aqueous solution containing 25% iodine by volume.
3. Aqueous solution containing 50% iodine by volume
4. Bladder containing several radiolucent pellits and an aqueous solution with 25% iodine.
5. Aqueous solution containing 25% iodine
6. Aqueous solution containing 50% iodine
7. Aluminum step-wedge type penetrometer
8. Suspension of $BaSO_4$ in heavy molasses with two nodules attached to inner wall.
9. Proximal end of human femur
10. Flotation chamber sealed against electrolyte medium and communicating with the external surface of the phantom
11. Electrolyte solution contained within phantom
12. Radiolucent plastic container



Isometric Drawing of

Experimental Phantom